Magnetism

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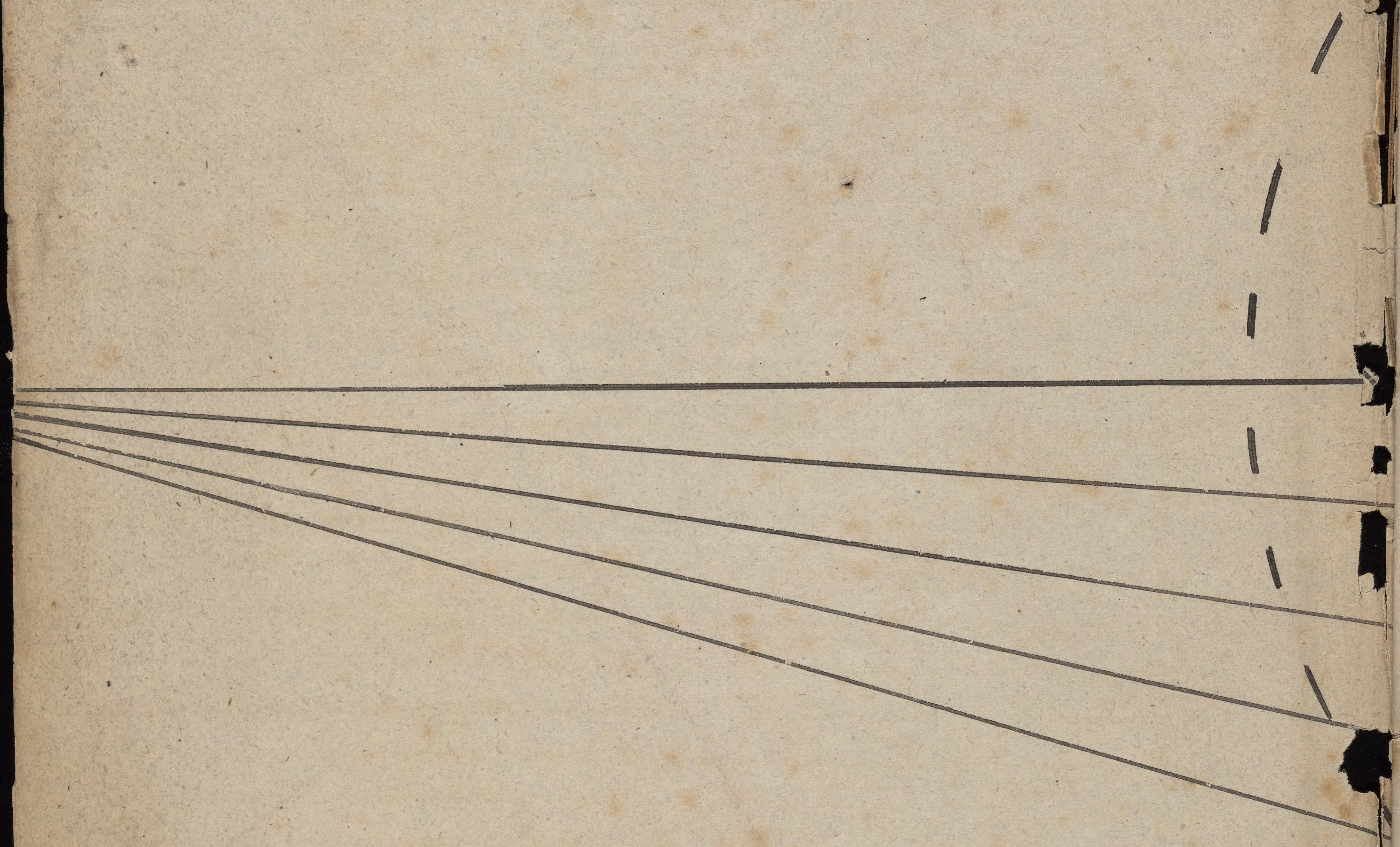


Magnetism.

1. If a bar of steel be held in a vertical position and struck several times with a hammer, it will attract any small piece of iron presented to either of its extremities: the property thus acquired by the bar is called Magnetism and the bar itself ~~is said to be rendered~~ a Magnet. We shall presently describe more convenient methods of communicating magnetism to iron and steel but for the present we may suppose that all the magnets which we employ in our experiments have been made in the manner just described, for the properties of a magnet are exactly the same, in whatever manner the magnetic property may have been communicated to it.

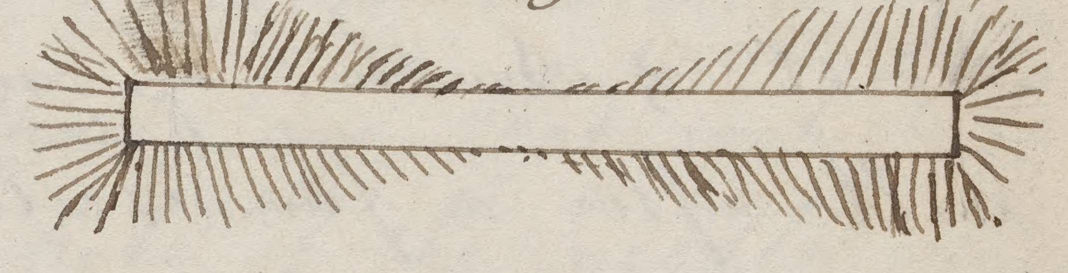
2. The most striking property of a magnet is its power of attracting iron; magnets are easily obtained which exhibit this power in a very ~~high~~ remarkable degree. A bar of steel about 18 inches long, may be magnetised so as to support at either of its extremities a piece of iron weighing 3 or 4 oz. A magnet of the same length bent into the form of a horse-shoe with its extremities about an inch apart will support a piece of

iron weighing 3 or 4 pounds placed across its extremities.

3. If a small piece of iron be placed within a short distance of either extremity of a magnet, it will be drawn towards the magnet; — this result shows that the power of a magnet is exerted upon iron at a distance as well as when they are in contact. — If a needle be suspended vertically by a fine thread and the pole of a magnet presented to it at various distances it will be seen that the power with which the magnet attracts the needle diminishes as the distance between them increases. If the magnet be fixed at a certain distance from the needle, and a plate of glass, wood, copper, or any substance excepting iron be interposed between them, the needle will be as much deflected from the perpendicular when these substances are interposed as when they are removed: but if a plate of iron be interposed the needle will immediately fall down to its natural position. Hence, we conclude that the magnetic power can act through any substance excepting iron.

4. If we take a piece of iron of such a size that it can be easily supported by the extremity of a bar-magnet, and holding the magnet horizontally gradually move the iron from the extremity towards the middle of the magnet, we shall find that as ~~it~~ the iron recedes from the extremity, it will be less firmly held by the magnet, and when it arrives at a certain distance from the extremity, it will fall off: this experiment clearly shows that the ~~power~~ different parts of the magnet differ greatly in attractive power: the difference may be strikingly shown by rolling the magnet in iron filings: ~~the magnet~~ it will, when taken out, present the appearance shown in Fig 1.

Fig 1.



the filings adhering in large quantities round the ~~ends of~~ ~~the magnet~~ extremities, and leaving the middle quite bare. —

It has been found by careful experiments that the parts of a magnet which possess the greatest power are situated at about 2 inches from the extremities, in bar magnets of the length of 6 inches and upwards; ~~and~~ in those which fall short of that length, the greatest power is situated at a distance from ~~the~~ each extremity equal to one third of the length ~~of the length~~ of the bar. The points of greatest power are called the poles of the magnet. Between the poles there is a portion totally destitute of magnetic power: this portion forms a line encircling the magnet: it is called the Median line:

the two ~~portions~~ halves of the magnet on either side of the median line are also called the two poles of the magnet: it is always easy to distinguish whether the term pole is used in this, ~~sense~~ or ~~in~~ the more exact sense already mentioned:

5 If a bar magnet be suspended by a fine thread attached to its centre, so as to balance it nicely and give it great freedom of motion, it will arrange itself in a particular direction, its extremities pointing nearly North & South; if moved from this position, it will after a few oscillations arrange itself in the same manner as before. The most convenient arrangement for exhibiting this property consists of a bar magnet about 6 inches long, ~~called~~ having an agate cap C (fig 2) attached to its centre: this cap rests on a fine steel point. This instrument is called a magnetic needle; it is of great use in magnetic experiments. A suspended magnet always presents the same extremity towards the North: this property constitutes a marked distinction between the two extremities or poles of a magnet: that which points to the North is called the North pole, the other the South pole. It is usual to place

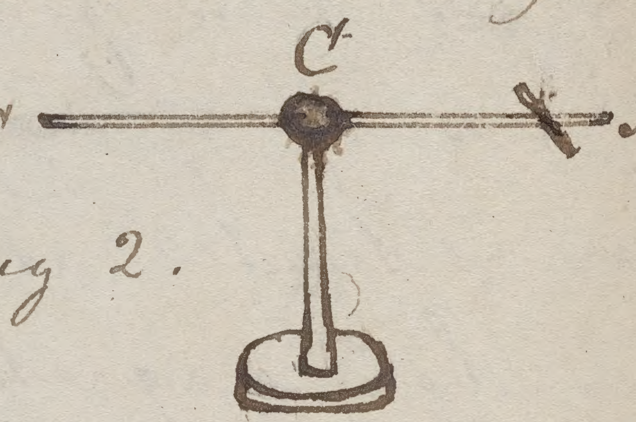


Fig 2.

a mark on the north pole of a magnet to distinguish ~~it~~ it from the South. In large magnets a groove is cut ~~round~~ near the extremity as at N (fig 3). The north pole of ~~in~~ small needles is marked by a cross piece ~~is placed~~ as shown in fig. 2.

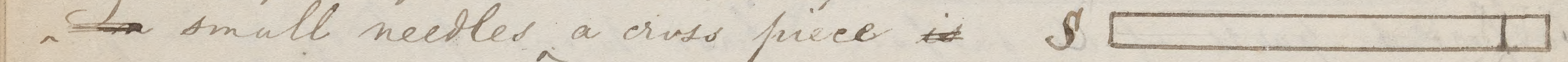


Fig 3.

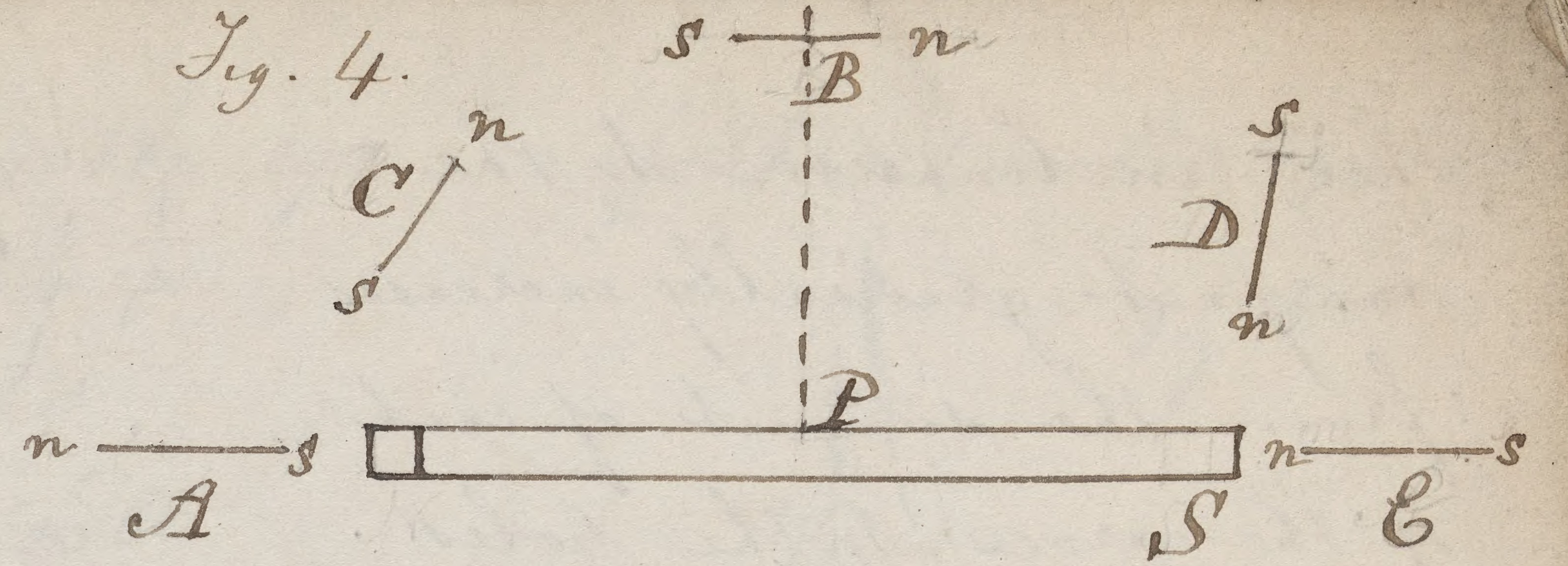
6. If a piece of unmagnetised iron be held near either pole of a magnetic needle, the needle will be attracted by the iron, ~~showing that th~~ but if a magnet be presented to the needle instead of the iron, it will be found that each pole of the magnet attracts one pole of the needle and repels the other; and that each pole of the magnet attracts that pole of the needle which the other repels. – Further, if the magnet be suspended horizontally ~~so as to~~ for the purpose of distinguishing its poles, it will be found that the north pole of the magnet repels the north pole of the needle and attracts the south; and that the south pole of the magnet repels the south pole of the needle and attracts the north: If instead of the needle, we make use of any bar-magnet suspended by a thread we shall find the same series of attractions & repulsions to take place between its poles & those of another magnet presented to it. – Hence we draw the important conclusion that the similar poles of magnets repel each other, but their dissimilar poles attract each other –

7. Since unmagnetised iron attracts either pole of a magnet we may always ascertain whether any particular piece of iron possesses magnetic properties by presenting the different parts of its surface first to one pole of a magnetic needle and then to the other: if the needle be always attracted, we may conclude that the iron is not magnetic, but if any part of it repel one pole of the needle and attract the other we may conclude that the iron is magnetic; and that the part which repels the north pole of the needle is itself a north pole, and that part which repels the south pole of the needle is itself a south pole.

8. By presenting the different parts of a bar magnet to the needle, we shall find that the north polarity extends over one half of the magnet and the south polarity over the other half, the two portions being separated by the median line at which no polarity exists.

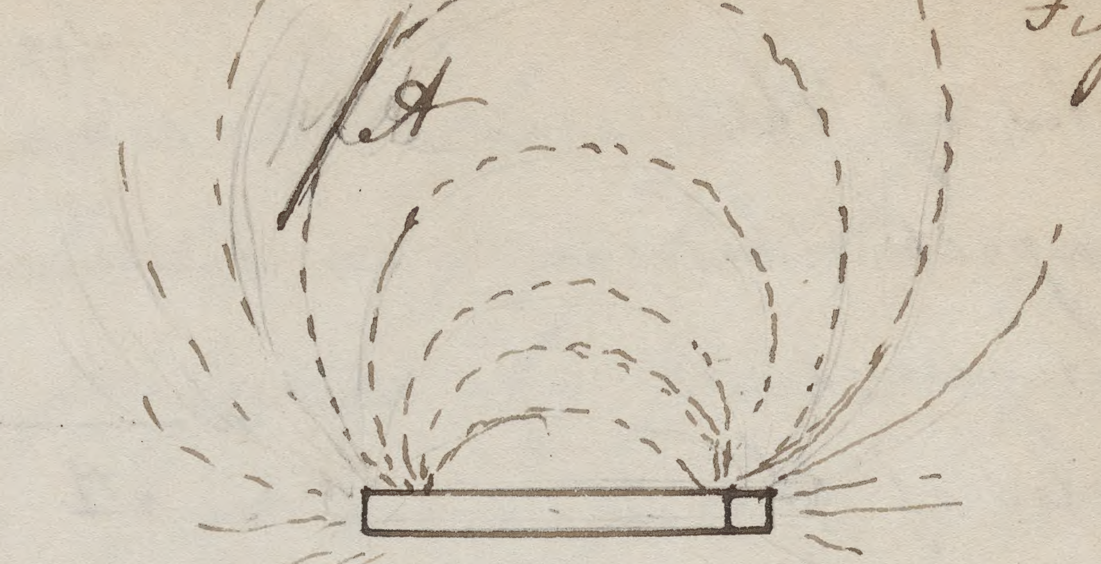
9. If a magnetic needle be placed in the neighbourhood of a large bar magnet, it will take up a certain position determined by the attractions and repulsions exerted between the poles of the two magnets; the direction in which the needle will arrange itself will vary with the directions in which these forces are exerted. Thus, if the needle be placed at A or E (fig 4) it will stand with its poles in the same straight line as the

Fig. 4.



poles of the magnet, the contiguous poles of the magnet & needle being of opposite names. If placed any where on a line ~~drawn~~ BP drawn from the middle of the magnet at right angles to its edge, the needle will arrange itself as at B, parallel to the magnet but having its poles turned in the contrary direction to those of the magnet. In any intermediate position as at C or D the needle will be inclined to the magnet. If the needle be gradually carried round the magnet beginning from A, and passing through C to B, D and E it will be seen gradually to change its position, passing through all the different degrees of inclination until it has turned half round and stands with its north pole towards the magnet as at E. These different positions are well exhibited by placing the magnet NS under a sheet of smooth paper, and strewing iron filings on the paper through a gauze sieve. The filings will arrange themselves as so many small needles, and will be disposed in curve lines as represented in Fig 5. By examining the position of the minute pieces of iron in each of these curves, it will be seen that

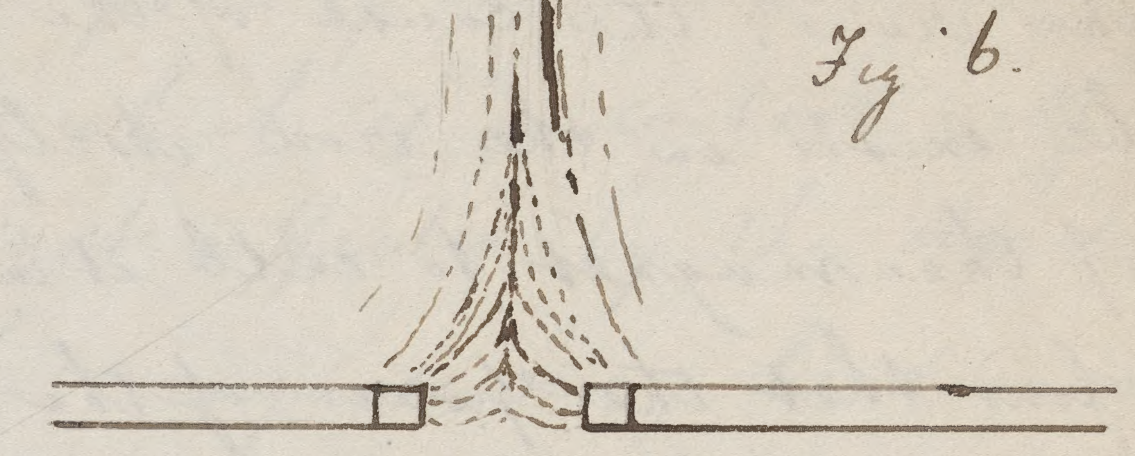
Fig. 5



their inclination to the magnet gradually increases from the summit of each of the curves to the poles of the magnet. If a small needle be placed with its centre over any part of one of these curves as at A it will arrange itself in the direction of the tangent to the curve at that point. The curves formed in the above manner are called the Magnetic curves: they are possessed of some remarkable mathematical properties of great importance in the theory of Magnetism; but the discussion of these properties is foreign to our purpose. To exhibit the form of the curves to advantage, the magnet should not be more than 6 or 7 inches long, otherwise the curves are not well defined towards the middle on account of the distance of the poles: a horse-shoe magnet exhibits the curves much better than a bar, the poles of such a magnet being very close together. If two bar magnets be placed under the paper with their opposite poles facing each other and about two inches apart, curves will be formed bearing a very close resemblance to those formed by a single magnet; their form is however slightly modified by the action of the remote poles of the magnets, but the difference

cannot be detected by the eye. If the similar poles of the magnets be placed facing each other, the form of the curves will be entirely changed, they will assume the appearance delineated in fig 6.

Fig 6.



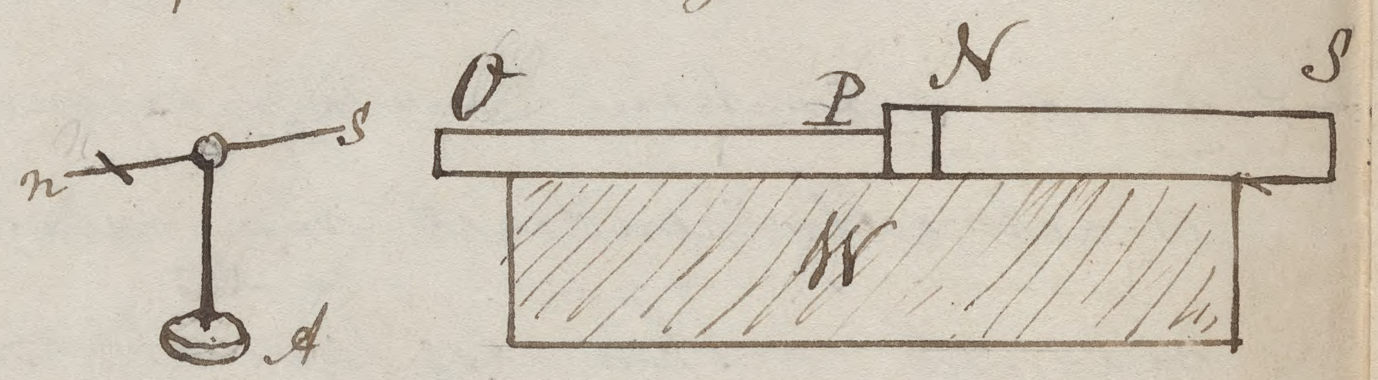
10 We have said that each of the filings arranges itself in the same manner as a magnetic needle placed in the same situation: we may now add that each of them is actually rendered magnetic by the influence of the magnet: this leads us to treat of Magnetic Induction

11. If we take a piece of soft iron, ascertain that it is totally destitute of magnetic power, (7) and then place it in contact with either end of a powerful magnet, we shall find that it has acquired the power of attracting any small piece of iron presented to it; thus, if its ~~the~~ extremity be dipped in iron filings, the filings will adhere to it and will continue to do so as long as it remains in contact with the magnet, but the instant the contact is broken, the filings will all fall off. It is plain then that the iron is possessed of magnetic power while in contact with the magnet, but that it loses this power as soon as the influence of the magnet is removed. From this latter circumstance it follows

that nothing has been <u>communicated</u> from the magnet to the iron; the cause of the magnetic power, whatever it may be, exists in the iron itself and requires but the influence of the magnet to call it into activity. We shall presently find that the power of the magnet is not diminished but increased by the contact of the iron.

12. Let us now examine the <u>polarity</u> of the iron when in contact with the magnet; For this purpose let a magnetic needle be placed at such a distance from the iron as not to be disturbed from its ordinary position (5) by the attraction of the iron: it will be convenient to support the iron on a block of wood so as to bring it to a level with the needle: the arrangement is represented in Fig 7: OP is a bar of iron 6 or 8 inches long, supported on a block W: the needle is placed at A. – Let the north pole of a magnet be placed in contact with the end P of the bar; immediately the south pole of the needle will turn towards O: on the removal of the magnet the needle will resume its ordinary position: now let the south pole of the magnet be placed in contact with P: the north pole of the needle will immediately turn towards O

Fig 7.



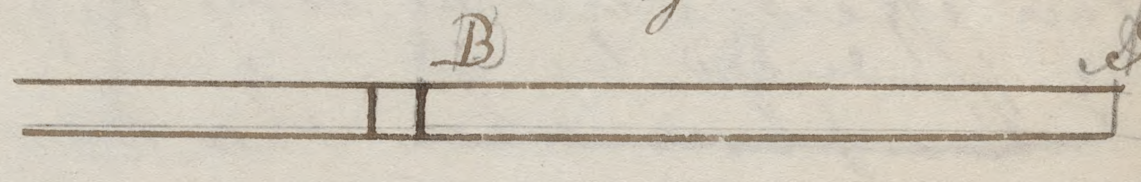
Hence then, the extremity of the iron which is farthest from the magnet becomes a pole of the same name as that pole of the magnet which is in contact with the iron. That the needle is not affected by the direct influence of the pole of the magnet may be demonstrated by removing the bar OP and leaving the magnet in its place; the needle will immediately return <u>towards</u> its natural position; we say <u>towards</u> because the magnet may have some effect on ~~it~~ the needle: but this effect will be very trifling compared with that which ~~takes place when~~ is produced by the bar OP ~~is returned to its place~~.

13. The magnetisation of the iron may be effected without actual contact with the magnet. To demonstrate this fact, let the magnet be <u>gradually</u> moved towards the bar OP; ~~when the distance between the deflection of~~ the needle will ~~begin~~ be deflected when the magnet has approached within a certain distance of P, the deflection will continually increase as the ~~distance diminishes~~ magnet approaches, and will be greatest when it is in contact. As the magnet is removed, the needle will gradually recover its ordinary position.

14. If a bar of steel about 4 inches long and not very hard, be placed in contact with the pole of a magnet, it ~~which~~ will acquire the magnetic

power in the same manner as the soft iron: but it will not lose this power when removed from the magnet: on the contrary, it will still attract iron, and on presenting its two extremities to the poles of the magnetic needle, it will be found that the the extremity which has been in contact with the pole of the magnet is a pole of the contrary name, and the other extremity a pole of the same name: for instance, if ~~the end~~ AB (fig 8) be ~~of~~ a steel bar ~~which has been~~ in contact with the north pole of a magnet

Fig. 8.



the end B becomes a south pole and the end A a north pole. We see then that the polarity of the farther end of the bar is the same whether the bar be of steel or soft iron. It is difficult to examine the polarity of the end of a bar of soft iron in contact with a magnet because a needle presented to that extremity will be powerfully influenced by the pole of the magnet itself; and when the magnet is removed, the polarity of the iron is destroyed: but if we place a bar of soft iron at the distance of an inch or so from the pole

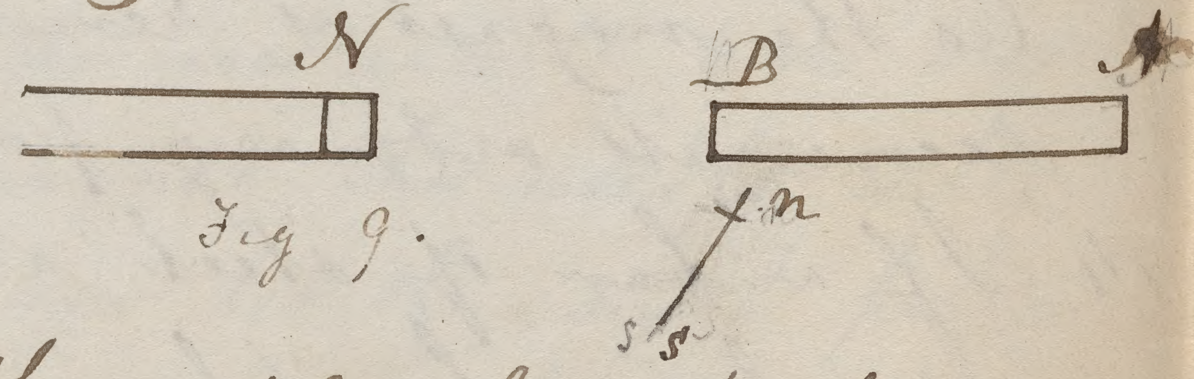


Fig 9.

N of the magnet and place the needle close to the end B we shall see that the north pole of the needle tends

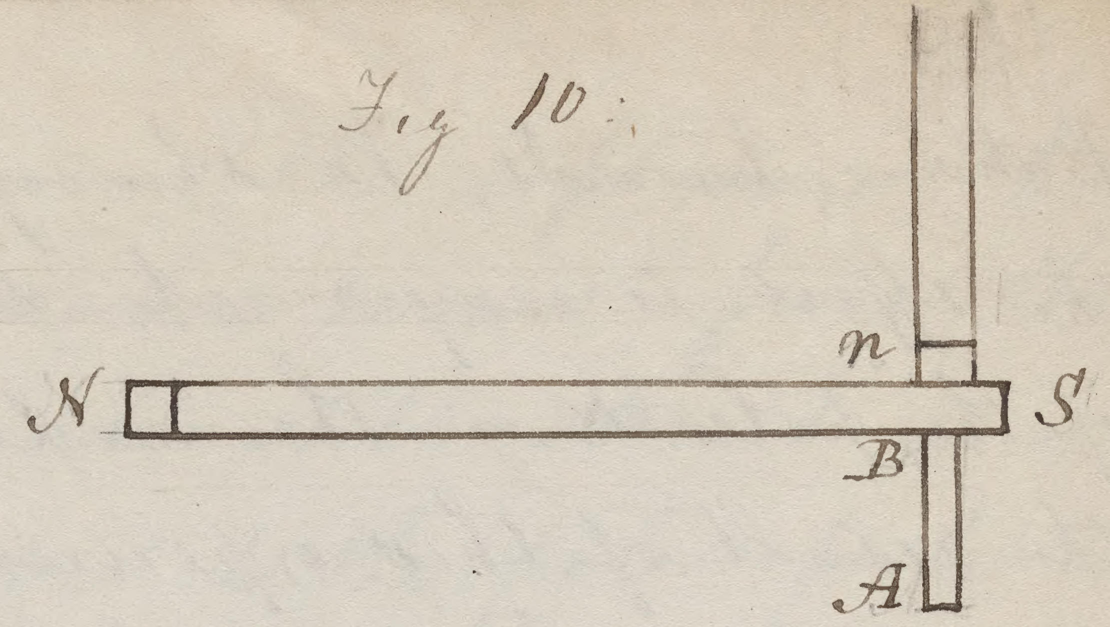
to turn towards B shewing that B is a south pole, but the effect is very much ~~dispose~~ disguised by the direct action of the pole N on the needle: when however we compare the result of this experiment with what takes place in a steel bar similarly treated, we can have no doubt that the end B becomes a south pole. —

15 The developement of magnetism in iron and steel by the influence of a magnet is called the Induction of Magnetism: the law by which it is regulated may be thus stated. — A piece of iron placed in contact with, or in the neighbourhood of, the pole of a magnet, becomes itself a magnet, and its polarity is so disposed that the magnet and the iron ~~mutually~~ attract each other. ~~for the contiguous extremities of the iron and the magnet possess opposite polarities and the dissimilar poles of magnets attract each other.~~

16. We may thence infer that the attraction of the magnet for iron is merely a particular case of the general law that the dissimilar poles of magnets attract each other, for the part of the iron nearest to the magnet always possesses a polarity contrary to that of the pole of the magnet which acts upon it. That this is the real cause of the attraction of the magnet for iron may be proved as follows. Let a bar magnet

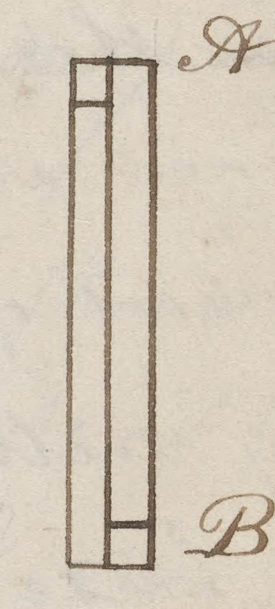
N S (fig 10) be placed horizontally and a piece of soft iron A B suspended from one of its poles, S for example; then let the north pole n of another magnet, of the same power as the first, be brought into contact with S; the iron A B will instantly drop off: to explain this effect, we must observe that the south pole of the first magnet N S induces north polarity in the iron at B and ~~south~~ south polarity at A, and the attraction between the opposite poles S and B is sufficient to sustain the weight of the iron: but when the pole n is placed in contact with S, it tends to induce south polarity at B and north polarity at A; hence the polarity originally induced by S is weakened, and that which remains does not give rise to an attractive power sufficient to support the iron. It must be observed that if the two magnets be of equal power, the effect of the pole S will not be entirely neutralised by that of n, for S is in contact with B and n is at a distance from it; indeed if the ~~weight of~~ A B be of small weight it will not drop off on the approach of n: it will however be separated from S much more easily than if n were not acting

Fig 10:



This experiment affords a convincing proof that the force with which iron is attracted depends on the intensity of the polarity developed in it. If a piece of hard steel be suspended from S and suffered to remain there for a few minutes, it will not drop off on the approach of n because the alteration of its polarity cannot be ~~produced~~ effected so quickly as in soft iron.— If the south pole of the second magnet be placed in contact with S, the force with which the bar A B is held will be increased, because the two magnets will then conspire in producing the same polarity in it.—

The principle just established may be further illustrated by taking two bar magnets of equal size and power, and placing them, as in fig 11, with their opposite poles in contact; we shall find that when held vertically they will scarcely support the smallest piece of iron from either of the extremities A or B; but if placed with their similar poles in contact they will form a compound magnet ~~of~~ the power of which will be greater than that of either of the magnets separately. But the effect will be very different if the magnets be separated and their poles applied at the opposite extremities of a piece



of iron ~~as in fig. 12~~. Thus if the opposite poles N, S (fig. 12) be applied to the extremities A B of a short bar of iron, N will produce a south pole at A and a north pole at B: similarly, S will induce north polarity at B and south at A: the two magnets will thus assist each other in magnetising the bar and will therefore support it: but if the similar poles of the magnets be applied at A and B, they will act contrary to each other, tending to magnetise the bar in contrary directions, and the bar will consequently not be supported by them. The poles of a horse-shoe magnet act on a piece of iron placed across them, just like the dissimilar poles of two bar magnets; ~~For this circumstance explains~~ hence arises the great sustaining powers of magnets of this description.

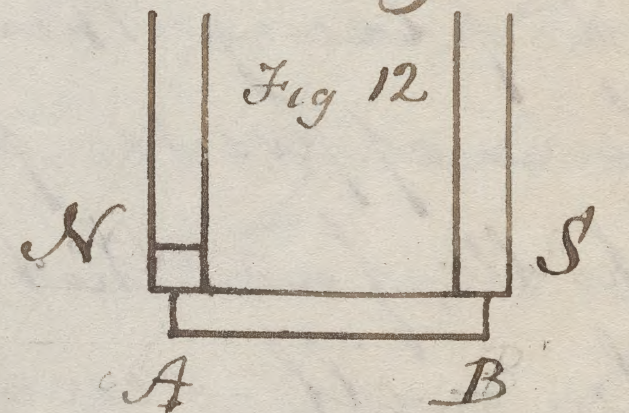
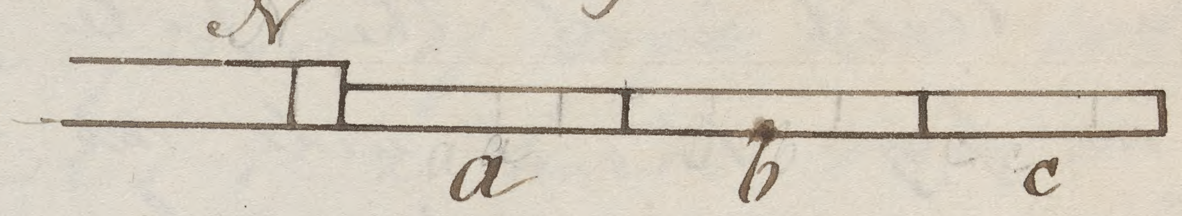


Fig 12

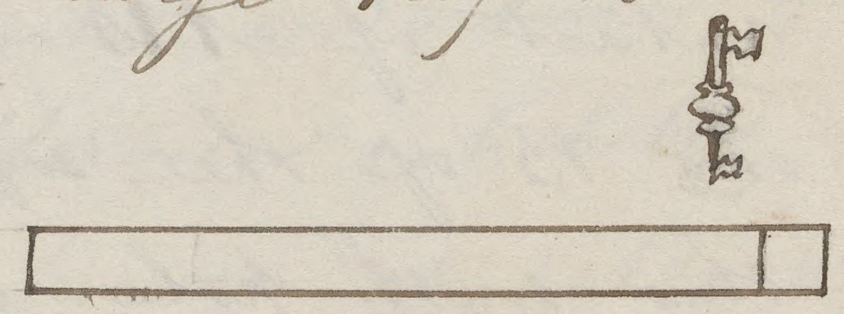
By rivetting together a number of horse-shoe magnets, taking care to place all the similar poles on the same side, compound magnets may be formed capable of sustaining enormous weights.

16. A piece of iron magnetised by induction will act on another piece of iron in the same manner as if it were an independent magnet: thus, if a number of pieces of soft iron a, b, c be placed together as in fig. 13. a being in contact with the north pole N of a magnet, they will all attract iron filings and repel the north pole of a magnetic needle.

Fig 13.



It may perhaps be imagined that they are all magnetised by the direct influence of N, but it is easy to prove that but a very small portion of the effects is due to this cause: for if a and b be removed, and c retained at the same distance from N, its power will be almost ~~disappear~~ entirely destroyed. A variety of experiments may be devised to illustrate the principle just explained: thus, if a piece of iron be suspended from the pole of a powerful magnet, a second piece may be suspended from the extremity of the first, a third from the second and so on: by continually diminishing the weight of the pieces, the chain may be extended to a considerable length. If the end of a magnet be dipped in iron filings and gradually lifted up, a long string of filings may be drawn up after it. If a large key be held above the pole of a bar magnet placed horizontally as in fig. 14. a small key may be suspended from its lower extremity; because

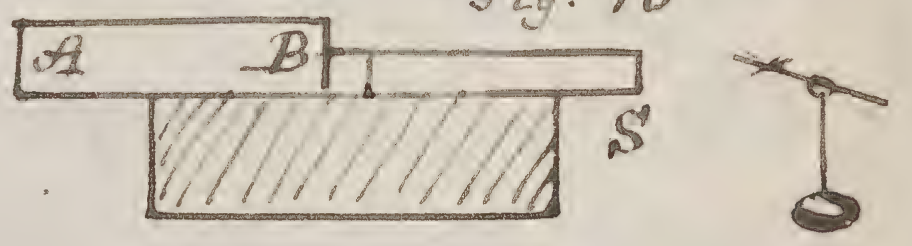


in this arrangement, the ends of the two Keys which are in contact possess opposite polarities but if the large Key be placed on a level with the pole as in fig. 15 it will no longer support the other, because the contiguous ends of the two Keys are then endued with the same polarity.

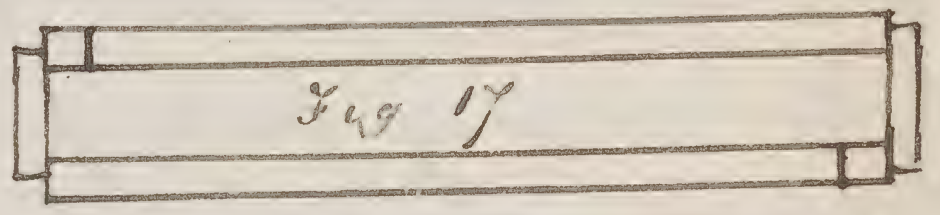
Fig. 15

17. The inductive action of a piece of iron magnetised by juxta-position with a magnet is exerted on the magnet itself as well as on other pieces of iron; this may be proved as follows. Let a small magnet of soft steel be fixed on a block of wood D (fig 16) and a magnetic needle n s placed at such a ~~a short~~ distance from it as to deflected slightly from its ordinary position, the north pole turning towards S: then let a large piece of soft iron A B be placed in contact with N: the deflection of the needle will immediately increase showing that the power of the magnet N S is increased by the contact of AB: this effect is easily explained the end B of the soft iron becomes a south pole, and this south pole strengthens the north polarity of N and the south polarity of S acting in the same manner as if it were the south pole of an independent magnet.

Fig. 16



18. From the preceding explanation it may easily be inferred that a piece of iron placed in contact with a magnet always increases its power; hence it is usual to place a piece of soft iron called a Keeper across the poles of a horse shoe magnet when not in use. and to arrange bar magnets in pairs with their contrary poles towards each other and similar Keepers placed across the poles; this arrangement is shown in fig. 17.



19. We have seen ~~that~~ in several experiments, that steel which has been magnetised by induction retains its power after removal from the magnet, whereas soft iron instantly loses that power when the exciting cause ceases to act upon it: hence it is that magnets are always made of steel. The various methods of making magnets are merely modifications of the general principle of induction; but before entering upon the explanation of these methods, it will be necessary to make a few observations on the manner in which magnetic induction takes place in steel. The difference exhibited by soft iron and steel in the power of retaining magnetism is scarcely more remarkable than the different degrees of facility with which they

receive it. Soft iron is instantly susceptible of the magnetic influence: if a bar several feet in length be placed in contact with th pole of a magnet a needle placed at its farther extremity instantly indicates the existence of a polarity similar to that of the inducing pole. But in steel the induction is the work of time: if a bar of steel about a foot long be placed in contact with the pole of a magnet, the farther end will, for a long time, exhibit no signs of magnetic power, but if the needle be placed near the bar at the distance of about 2 inches from the pole of the magnet it will be seen that the induction is progressing: by moving the needle along the bar from time to time, it will be seen that the polarity is gradually extending toward th farther extremity: If the steel be very hard, the farther end will not be affected for 2 or 3 hours nor will the full effect of the magnet be produced for several days— The harder the steel the greater is the resistance which it opposes to the developement of the magnetic power and the greater also is the tenacity with which it preserves that power. Hard wrought iron is intermediate in its magnetic properties between soft iron and steel: cast iron exceeds even steel

in its retaining power, but it is not found to be so well adapted for making magnets: for what reason is not very clearly ascertained.—

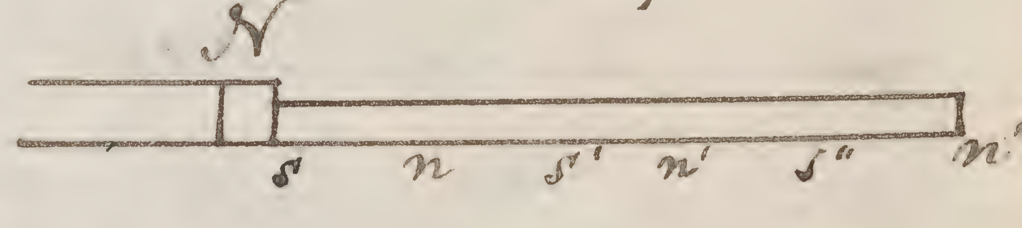
21. There are a variety of circumstances by which the retaining power of iron and steel may be modified: thus for instance, if a magnet be hammered, or thrown on the ground, or subjected to any treatment which produces a concussion of its particles, its power will be impaired: this will be particularly the case if the blow be of such a nature as to produce a ringing sound indicating that the particles of the steel are thrown into rapid vibration. Again, we have seen that soft iron is incapable of retaining magnetism; but it is only when the iron is absolutely pure, free from the slightest trace of foreign matter, that its retaining power is absolutely nothing: it is extremely difficult to procure a piece of iron totally incapable of retaining the magnetic power, and even when such a piece is obtained, any treatment, such as twisting or hammering, by which its texture is altered, at once renders its capable of retaining magnetism. The same causes which influence the retaining power of iron and steel exert a contrary influence on their capability of receiving magnetism: thus, when a bar of steel is placed

in contact with a magnet and hammered, the induction will proceed more rapidly than when the steel is left to itself.

21. But of all the causes which modify the magnetic properties of iron and steel, the most influential is heat. Within certain limits, an increase of temperature increases the susceptibility and diminishes the retaining power: thus, if a magnet be gently heated, it will be found to have less effect on a needle placed at a given distance from it, than it has when cold: if it be then suffered to cool, it will regain its power: but if it be heated to redness, its power will be completely destroyed and will not return when the magnet cools. It has been found that a mass of iron raised to a red heat is more susceptible of magnetic induction than at ordinary temperatures, but when raised to a white heat, it becomes totally indifferent to the action of the magnet.

22. We now proceed to describe the methods of making magnets. ~~The properties of greatest importance in a magnet power~~ The chief points to be attended to in this process are, 1st to develope the highest degree of magnetic power; and 2ndly to distribute that power with the greatest regularity — the power of a magnet is said to be regularly distributed when the poles are at the same distance from the extremities and the median line exactly midway between them. Now we have seen that a bar of steel may be magnetised by simply placing it in contact with the pole of a powerful magnet: but this is a very imperfect method, for the resistance of hard steel to the developement of magnetism is such, that the polarity will frequently extend no farther than the middle of the bar: thus supposing A to be a bar of steel in contact with the north pole of a magnet it may happen that the north polarity of the steel may never extend farther than n; and when this is the case, it frequently happens that the portion of the bar s n acts like a separate magnet on the remaining portion, and produces a south pole at s' and a north pole at n' and this portion may produce a third south pole at s" &c. Poles developed in this manner are called consecutive poles.

Fig 17'



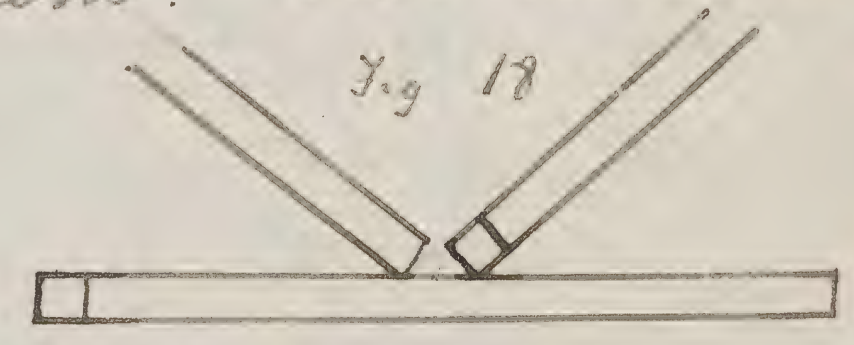
A more effectual method of obtaining regular and powerful magnetisation is to place the bar between the opposite poles of two powerful magnets as shown in fig 17": this method answers very well for short bars not exceeding 6 inches in length, but it is totally inadequate for magnet-

Fig 17"

bars of larger dimensions: for this latter purpose two methods are employed, which are distinguished by the names of the Single and Double Touch: each of these is susceptible of several modifications: we shall confine our observations to those which are most generally employed in practice.

23. *Magnetisation by the Single Touch*. The inapplicability of the last-described method to the magnetisation of large bars arises from the resisting ~~offered by the steel~~ power~~ful~~ (or as it is generally called, the *coercive* power) of the steel, in consequence of which the influence of the magnets cannot extend beyond a short distance from the extremities of the bars placed between them: this inconvenience may be obviated by placing the opposite poles of the magnets on the middle of the

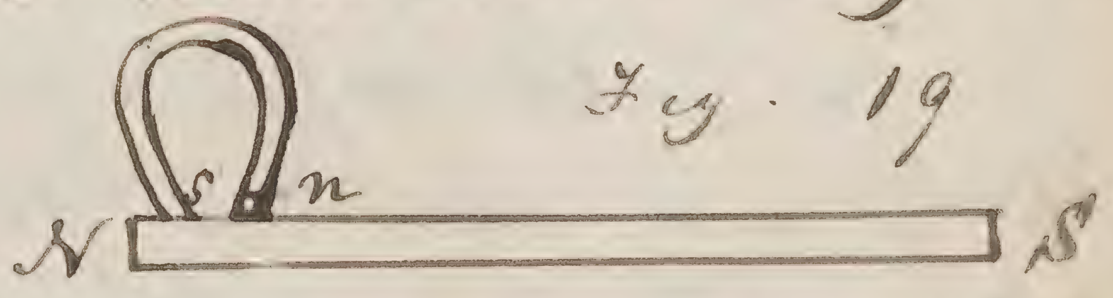
Fig 18



bar N S fig. 18 and then moving them with a regular motion from the middle to the extremities; the end of the bar over which a north pole has travelled will be a south pole and vice versâ: the motion should be repeated 8 or ten times ~~for~~ on each surface of the bar, and the magnets must always be moved the same way, that is always from the middle to the extremities. The efficacy of this process may be greatly increased by ~~tt~~ magnetising two bars at a time and arranging them as in fig. 17. with pieces of soft iron placed across their extremities: the striking of the bars is then to be performed in the manner just described, care being taken to magnetise the two bars opposite ways, so that the ends touching the same piece of soft iron may have opposite polarities. The use of this arrangement may be understood from what was said in art 17.

24. *Magnetisation by the Double Touch*. In the process described in the last article only one pole of a magnet is employed in inducing magnetism on each half of the bar, at least the action of the more distant pole is very small compared with that which traverses the part in question: but in the process which we are now to describe two opposite poles are made to act at once on the same part of the bar: hence this process is called the Double Touch: the most convenient way of executing it is to take a horse-shoe magnet such as n s (fig 19) & move it along the bar from N to S and from S to N alternately:

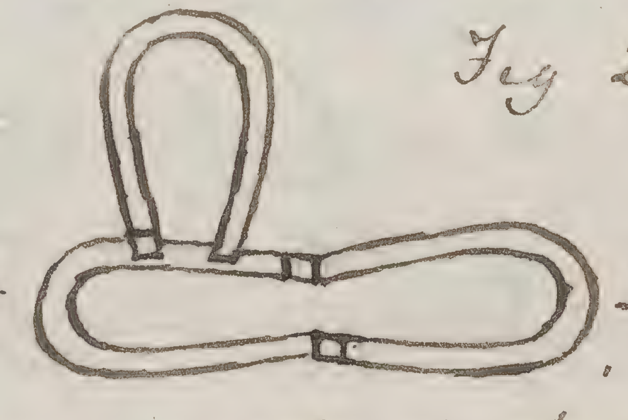
Fig. 19



the south pole of the horse-shoe magnet must be turned towards that end of the bar which is intended to be the north pole: for it is evident that when the magnet is at

N and its poles arranged as in the figure, both these poles conspire in producing a north pole immediately under ~~S~~ s: and when the magnet has moved on to S, the actions of both its poles conspire to produce a south pole at that end of the bar. [We must refer to a future article for a more particular <u>explanation</u> of this process, as well as of that of the single Touch.] When the process of the double touch is to be applied to straight bars, they should be arranged as in fig. 17, and the magnet carried round the circuit in one continuous direction. When horse-shoe magnets are to be made, two bars of that shape should be placed together as in fig 20, and the magnet n.s carried round them in one constant direction: the number of revolutions necessary to complete the process will depend on the hardness of the steel to be magnetised and the strength of the magnet employed. When the magnetisation is completed, the bars A B are not to be separated immediately, but soft iron Keepers must first be placed across the poles of each of them: by this ~~f~~ means, power is preserved which would otherwise be lost in the

Fig 20

A  B

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separation of the magnets. The process of the double touch is very efficacious in producing powerful magnets, on account of the combined action of the two poles on the part of the steel bar between them; but as far as regards <u>regular</u> magnetisation this process is not to be depended on with so much certainty as that of the single touch.

25. The degree of magnetic power which can be communicated to steel by the process just described appears to be limited by nothing but the strength of the magnet employed: but it is otherwise with the degree of power which the steel is capable of retaining: however great may be its hardness, there is always a limit to its retaining power: if a straight bar of steel after being strongly magnetised, be left to itself, its power will rapidly decrease: the diminution will go on for several days becoming gradually slower and slower, until at last it will entirely cease, & the power of the bar will then undergo no farther change: when bar magnets are kept in the manner described in article 17 they retain a much higher power than when left by themselves. A horse-shoe magnet loses a great deal of its power on the first removal of the Keeper after the process of magnetisation

A magnet of this description, which will support a weight of 60 lbs before the first removal of the Keeper, will perhaps not support 50 after its contact with the Keeper has been once broken. If the magnet be left without its Keeper its power will suffer a still farther diminution.

26. Whatever means we employ for inducing magnetism in iron or steel, we always find that a magnet has at least two poles: to make a magnet with only one pole is an absolute impossibility. But suppose that we take a bar magnet regularly magnetised and break it across the middle: we might expect to obtain two magnets, one of which should exhibit north and the other south polarity throughout its whole length: but this is not the case; on the contrary, each half becomes a perfect magnet with two poles and a median line between them: if ~~#~~ each of the pieces be divided, each fragment will also be a perfect magnet: and ~~generally~~ universally, into how many pieces soever a magnet may be divided, each fragment will be a perfect magnet having a north and a south pole. This circumstance may be accounted for by supposing that each of the minute particles of iron or steel of

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which the mass of a magnet is composed, is itself a perfect magnet. in other words that a magnet is an assemblage of minute magnetic particles arranged as in AD fig 21. ~~W~~, having all their similar poles turned the same way.

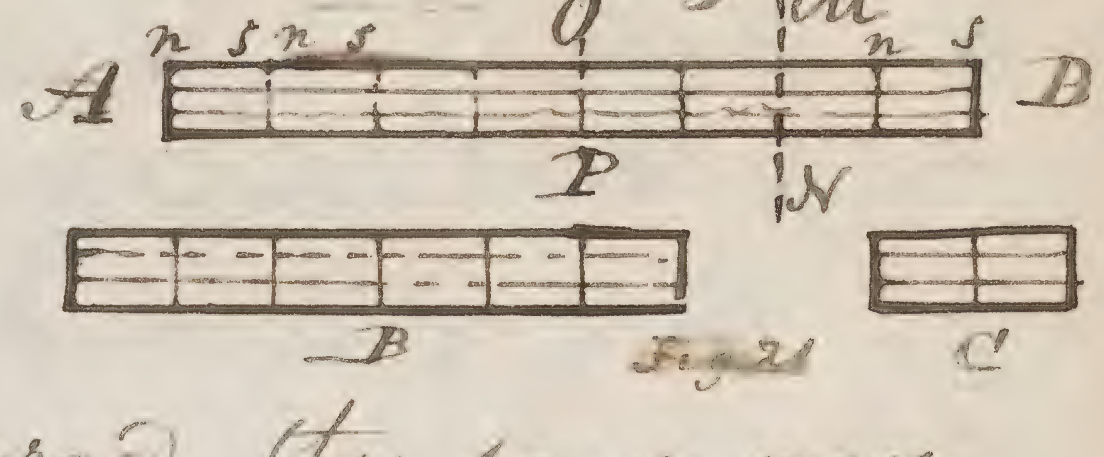


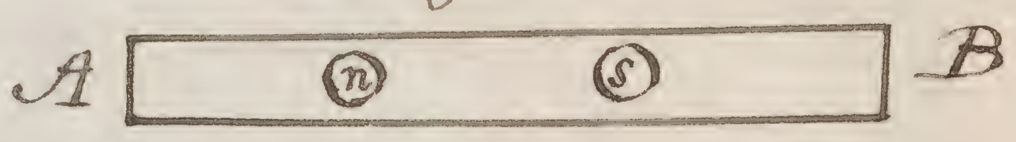
Fig 21

It is evident that if such an assemblage of particles be divided in any part at right angles to its length as at M N. each of the divisions B. C will bear an exact resemblance to the whole: we may therefore admit this constitution of a magnet as a satisfactory explanation of the phenomenon in question provided we can demonstrate that such a constitution is consistent with the properties of a magnet previously demonstrated. Now it has been found by an accurate estimation of the attractive and repulsive forces exerted by an assemblage of particles like that in fig 21, on any magnetic ~~magnetic~~ particle placed within the sphere of their influence, that the total effect of all these attractive and repulsive forces is the same as would result, if the north polarity were confined to ~~one half of~~ the particles on one side of the median line OP, and the south polarity to the other half. The strict demonstration of this proposi-

is not of a nature to be introduced in this treatise, but we may obtain very good evidence of its correctness by the following experiment – Let a quantity of <u>steel</u> filings be enclosed in a glass tube, and the poles of a horse-shoe magnet passed along the tube in the same manner as if it were a steel bar to be magnetised, care being taken not to disturb the arrangement of the filings ~~in the tube~~; if a magnetic needle be then applied to the ends of the tube, it will be attracted and repelled by them as it would be by a bar magnet – in short, the tube, or rather the assemblage of filings contained in it, will be found to be a perfect magnet having <u>one</u> north & <u>one</u> south pole. if the tube be shaken so as to disturb the arrangement of the filings, its magnetic properties will entirely disappear. –

27. We may now attempt a more complete explanation than we have hitherto given of the changes which take place in the various processes of magnetisation When a bar of steel is laid between the dissimilar poles of two magnets, the minute particles of which it is composed are all magnetised with their poles in the same direction as those of the magnets themselves; ~~and~~ when the bar is not very long, this effect is easily produced throughout its whole length, but when the bar exceeds a certain length, the influence of the magnets on the particles near its centre ~~the middle of it~~ is not sufficient to give them a polarity equal to that of those particles which are nearer to the poles of the magnets: hence the magnetisation becomes irregular. this inconvenience is obviated by passing the poles of the magnets along the bar so as to bring each of the particles in succession under their influence: now suppose AB fig. 22. to be the bar, n, s, two magnetic poles in contact with any parts of its surface:

Fig 22.



the particles situated between n and s are magnetised with their south poles towards A and their north poles towards B; the particles between s and B & likewise those between n & A have their poles turned in the opposite directions, that is to say, their north poles towards A & their south poles toward B. but the particles between n & s are affected by the sum of the forces of n and s, while those situated on either side of the space n s are affected by the difference of those forces: hence the former are more powerfully magnetised than the latter: now, as ~~when~~ the poles n s move from their situat-

towards A and B, whether they move in the same direction as in the process

of the double touch, or in opposite directions as in that of the single, all the particles between n & A and all those between s and B must eventually come between them; and when any of these particles do come between them, they must be polarised in the direction opposite to that in which they were polarised when not between n & s; ~~but more powerfully~~ this second magnetisation will be more powerful than the first because the particles in question are now affected by the sum of the forces of n & s whereas they were before affected only by the difference of those forces. Hence all the particles of the bar become magnetised with their poles in the same direction. The advantage of the double touch consists in bringing the poles nearer together and thus making the sum of their actions greater and the difference less. —

28. There are other compounds of iron besides steel which possess the power of retaining ~~pow~~ magnetism: the most remarkable of these is the peculiar ore of iron commonly called the Loadstone — The magnetic properties of this mineral have been known for upwards of 2000 years: indeed the attraction of iron by the loadstone was the first magnetic phenomenon ever observed — The loadstone or natural magnet is an oxide of iron; it is found in almost all ~~various~~ parts of the world, ~~and~~ in masses ~~in masses~~ of various shapes and sizes and possessing different degrees of magnetic power. Some masses have been found capable of supporting weights of upwards of 100 lbs: the magnetic power is not however well developed when the mineral is in its ~~cr~~ crude state. it ~~is~~ requires to be cut & ground into regular shapes and fitted up in a particular manner with armatures of soft iron, a description of which may be found in Dr Roget's treatise on Magnetism arts. 216 ... 217.

29. There are ~~three~~ 4 metals besides iron which possess magnetic properties: these are nickel, cobalt, chromium and manganese: The magnet properties of nickel are very decided: it is not only attracted by the magnet but has also the power of retaining magnetism: magnetic needles have been made of it. Cobalt is strongly attracted by the magnet. The magnetic properties of manganese are asserted by some philosophers and denied by others; the probability is that some specimens of the metal are susceptible of magnetism.

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while others are not: the difference may depend on the state of aggregation of the particles of the metal*

Terrestrial Magnetism

30. We have seen that a magnetic needle removed from the influence of all masses of iron, magnetic or unmagnetic, places itself in a certain direction, its poles pointing nearly North & South. In London, at the present time, the north pole of the needle points about 24° west of the north point of the horizon. On this property of the magnet is founded the use of the well-known instrument called the Mariner's Compass; ~~and~~ by means of this instrument it has been discovered, that, in every part of the globe, the needle assumes a determinate position, but that its direction ~~varies with~~ is different in different places. There are certain places on the globe in which the needle points due North and South: these places are situated on a line encompassing the globe and called the Line of No Variation. Without endeavouring to trace the entire course of this line, suffice it to say, that, in one part of its course, it forms a portion of a great circle of the sphere passing through a certain point to the westward of Baffin's Bay, across the United States of America, touching the north-eastern point of the Continent of South America and thence passing into the south Atlantic Ocean. In the greater part of the hemisphere to the westward of this line, that is ~~to say which~~ including the continents of North & South America, the Pacific Ocean and the eastern part of Asia the needle ~~points~~ deviates to the east of the North; in the opposite hemisphere, including Europe, Africa and the Western part of Asia, the deviation is to the west. — A vertical circle passing through the direction of the needle at any particular place is called the Magnetic Meridian of that place; and the angle which this meridian makes with the diurnal meridian is called the Variation of the Compass.

31. The motions of a needle mounted as in the Mariner's Compass are confined to a horizontal plane: such an instrument is evidently incapable of indicating the existence of any force tending to place the needle in a position inclined to the horizon: but ~~if~~ suppose we take a bar of steel, perfectly devoid of magnetism, & mount it in such a manner that it may be supported by its centre of gravity & at the same time that it may have perfect freedom of motion in every direction; it will of course remain in any position in which it may be placed.

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* I have experimented with a specimen of perfectly pure manganese prepared in Mr. Everitt's laboratory and found it to have a decided effect on the magnetic needle

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if we then remove it from its bearings, magnetise
it powerfully, and then replace it; it will no
longer remain indifferently in any position which may
be given to it, but will arrange itself in the
magnetic meridian with its north pole inclined
downwards at an angle of 70° to the horizon — this
inclination is called the Dip of the Magnetic Needle.
It is by no means an easy matter to ~~to~~ mount a needle
in the manner above mentioned, but still it can be
done, and the result is such as above stated. An
instrument ~~fitted up~~ for exhibiting the Dip is called
a Dipping Needle — On carrying such an instrument
to different parts of the world, it is found that the
Dip is subject to still greater changes than the Variation.
On a certain line which encircles the globe and, in
some parts of its course, forms an arc of a great
circle, crossing the equator in certain points and
inclined to it at an angle of about 23°, the dipping
needle stands parallel to the horizon; in other words
it does not dip at all: this line is called the
Magnetic Equator of the earth. At all places
north of this line, the north pole of the needle dips
below the horizon, and at all places south of it,

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the south pole dips: the dip increases with the
distance from the magnetic equator on either side,
and in the northern hemisphere, at a point on
the line of no Variation, situated to the west of
Baffin's Bay ~~in~~ about 75° (A) north lat. the needle
stands exactly vertical.

32. On comparing the various observations relating to
the Dip and Variation, it will be found that the
direction of the needle may be accounted for
by supposing the earth itself to be an immense
magnet, having its median line coinciding with the mag-
netic equator, its south pole at the point in
the northern hemisphere at which the dipping needle
stands perpendicularly to the horizon, and its north pole
at a corresponding point in the southern hemisphere.
Navigators have not yet penetrated into the Southern
hemisphere far enough to determine the position of
this point.

33. The supposition thus suggested respecting the magnetic
constitution of the earth receives additional confirmation
from the experiment with which we began our in-
vestigation of the magnetic phenomena, viz. the mag-
netisation of a bar of steel

(A) The exact situation of this point was determined by Captain
Ross in his last voyage, and may be found in the pub-
lished account of that voyage —

by holding it in a vertical position and hammering it. – The object of hammering the bar in this experiment may be understood from the observations in art. 21. viz to overcome the coercive power of the steel: we may now shew that a bar of soft iron may be magnetised simply by being held vertically: if we hold a bar of soft iron in that position and present a magnetic needle to its lower extremity, the north pole of the needle will be repelled and the south pole attracted: contrary effects will be produced by holding the needle near the upper end of the bar: it is clear then that the bar is magnetised, its lower end being a north, and its upper end a south pole: if the bar be inverted, its polarity will be immediately changed, the north pole being still at the lower extremity: these results are exactly what might be anticipated, supposing the earth to be a magnet and its northern hemisphere to be endued with the same kind of polarity as the south pole of an ordinary magnet. The magnetisation of the bar in this experiment depends entirely on its position: the most powerful effect is produced by holding it in the direction of the dipping needle; but as this direction is, in our latitude, only 20° from the perpendicular, the effect in the vertical position is very nearly as great. If the bar be held at right angles to the direction of the dipping needle no polarity is induced upon it and when held horizontally the effect is too feeble to be detected without the use of a very delicate needle. – A bar of iron or steel heated to redness then placed upright and cooled rapidly by throwing water upon it, will be rendered permanently magnetic. Bars of iron which are constantly left in a vertical position, such as fire-irons & iron posts are almost always permanent magnets, their lower extremities being north poles. – The masses of iron in a ship are rendered magnetic by the earth's influence and thence derange the position of the compass needle. Serious accidents have at times resulted from this source of error: a very ingenious mode of correcting it has been proposed by Mr. Barlow, but it appears to be attended with certain inconveniences in practice which render it less generally available than was at first expected. ——

34. The general statement in art. 32 respecting the distribution of magnetic polarity over the earth requires some correction. We traced the course of the line of no variation from the magnetic pole westwards of Baffin's bay to the N. E. point of the continent of S. America and thence into the S. Atlantic Ocean: this is the only line of no variation in the western hemisphere; but in the eastern hemisphere the corresponding line after traversing the western part of New Holland enters the Indian Archipelago, where it divides into two branches one of which traverses the western part of Asia, and

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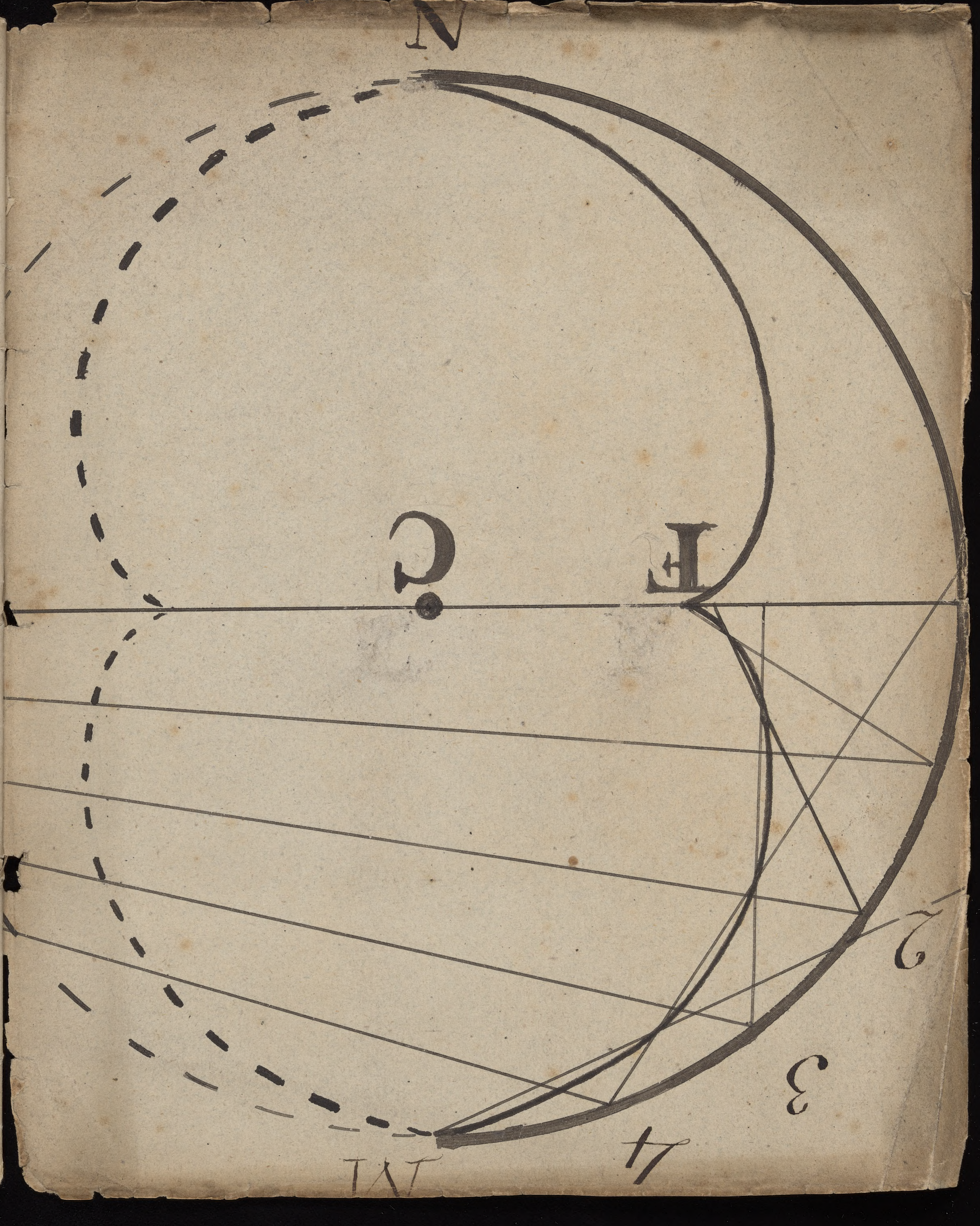
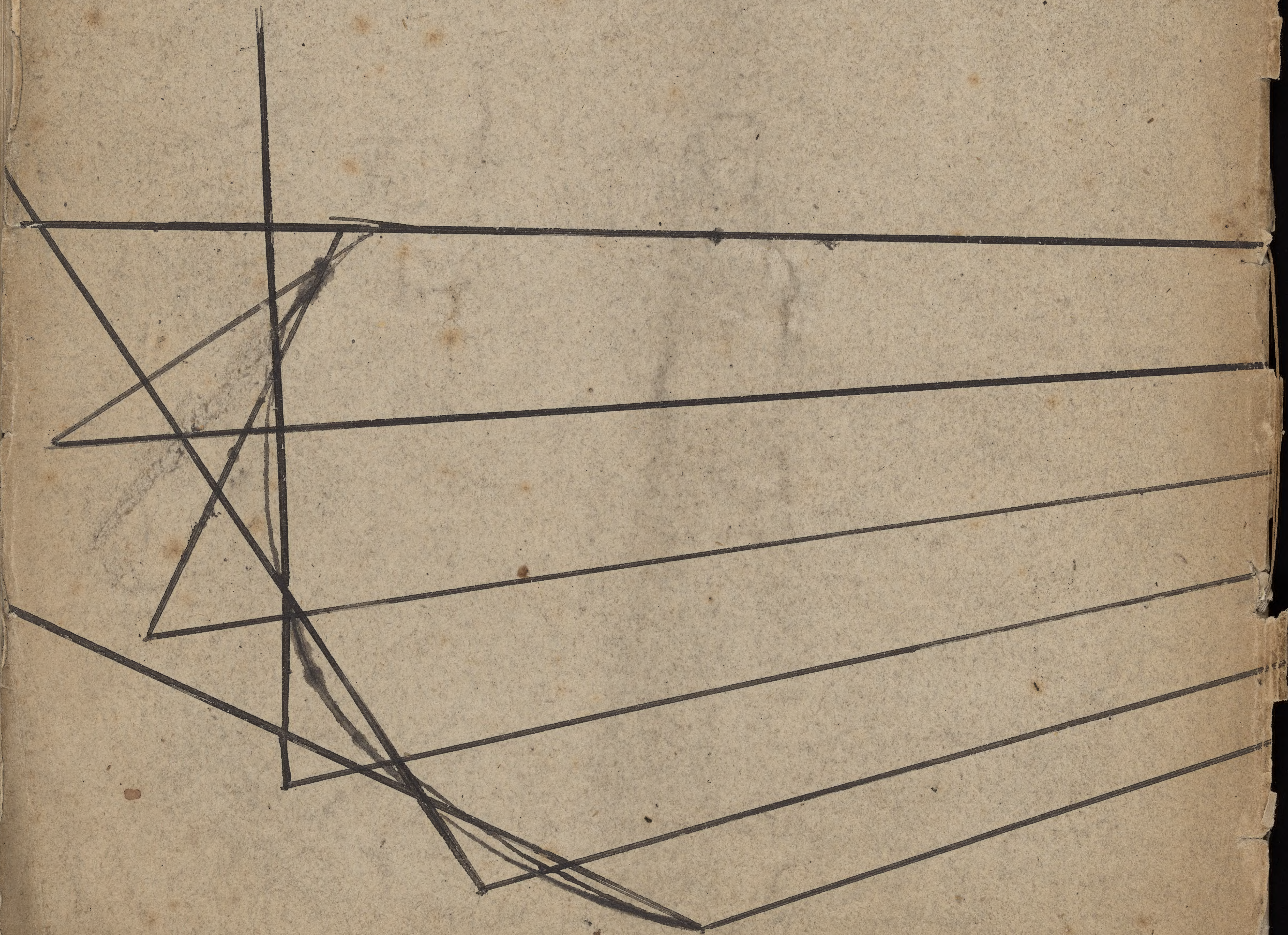
the other the eastern: the direction of the latter branch seems to indicate the existence of a second magnetic pole in the northern hemisphere situated somewhere in Siberia. If this be the case, there is most probably a second pole in the Southern hemisphere —

35. The Dip and Variation of the needle are constantly changing in all parts of the world. We shall ~~notice~~ confine our observations to the changes which have been observed in London — In the beginning of the seventeenth century the needle in London was inclined a few degrees eastward of the true north: in 1659 or 1660 it pointed exactly north, after which the variation became westerly and has continued so to the present time. We may hence infer that the position of the line of no Variation must be variable — The variation at London is at present about 24°. W. The dip was in 1680, 73° 30′, in 1723 it was 74° 42′, since which time it has been observed to diminish. In 1830 it was 69° 38′ —

36. The dip and variation are also subject to certain diurnal changes: these are very trifling, not exceeding a few minutes during the whole day; the diurnal changes of the variation are ~~much considerable~~ greater than those of the dip: the latter are exceedingly small — From observations made with very delicate horizontal needles, it appears that the deviation from the mean position is easterly during the fore-noon, and is of greatest amount about 8 o'clock; after that time the needle returns quickly to its mean position which it attains between nine and ten o'clock after which ~~it~~ the deviation becomes westerly: at first it increases rapidly so as to reach its maximum at about one o'clock in the afternoon; ~~and then~~ the needle then slowly recedes during the rest of the day so as to reach its mean position by about 10 o'clock at night.

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